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Factors Influencing Irrigation Technology Adoption and its Impact on Household Poverty in Ghana

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Abstract

The treadle pump technology was promoted and disseminated as an alternative to traditional rope and bucket for irrigation in Ghana by the International Non-Governmental Organization, Enterprise Works. The aim is to improve output, increase incomes and consequently reduce poverty among farm households. The paper employed the Heckman two-stage and the Ordinary Least Square procedures to identify the factors that influence adoption of the technology and the impact of adoption on the poverty status of farm households. Farm and household level data were obtained from 108 farmers consisting of 52 adopters and 58 non-adopters. The results demonstrated that availability of labor and increases in number of extension visits per year are factors that increase the probability of adoption. The results also showed that increase in irrigated area has the highest impact on poverty followed by adoption of treadle pump and literacy level of farmers.

Keywords: Irrigation technology, treadle pump adoption, poverty, Ghana

1 Introduction

The occurrence of erratic rainfall have created uncertainty for agricultural production and emphasized the need for irrigation in Africa. The traditional system of irrigation comprises of the use of either rope and buckets to lift and distribute water from shallow open wells or watering cans to lift water from streams. Although the low capital requirement of these traditional technologies makes them advantageous and affordable, their low delivery capacity and labor intensive nature make them highly unfavorable to African production conditions (Kamara *et al.*, 2004). Improved water lifting technologies, with relatively high efficiencies such as motorized pumps, have been tried but have been found to be favorable mostly to large-scale farmers. For small-scale farmers, who usually irrigate relatively small plots of land and operate relatively small capital, such technologies are unaffordable. This lack of simple, affordable and well adapted water development technologies, suitable to the production conditions and needs of smallholder farmers in sub-Sahara Africa, among others, is a serious handicap to efforts for achieving food security in the continent (Hyman *et al.*, 1995; Brabben and Kay, 2000).Today a substantial variety of low-cost, affordable water development options exist, including

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treadle pumps (TP [1]). The TP is a low-lift, high capacity, human powered water lifting pump. It is suitable for irrigating agricultural land of less than one hectare and are considerably less expensive than motorized pumps. Also, it cost much less to operate , having no fuel and only limited repair and maintenance costs. Its water lifting capacity of five to seven cubic meters per hour meets the irrigation requirements of most African farmers, the majority of whom cultivate less than one hectare of land. The pump is fabricated entirely from locally-available materials can be manufactured using welding equipment and simple hand tools in the metal workshops commonly found in Africa .The manufacturing, marketing and distribution campaigns of the treadle pump is carried out through development organizations. In Ghana, an international non-governmental organization, Enterprise Works promoted the use of treadle pumps to assist farmers improve their productivity and incomes. Treadle pump (TP) technology is widely believed to be a pro-poor, poverty alleviating technology due to its demonstrated potential for low cost irrigation, and suitability for small scale farming. The objective of this study is to identify the factors that influence the adoption of TP. It also explores the links between the adoption of TP and poverty status of small scale farmers.

2 Methodology

2.1 The Study Areas

The study was conducted in two Ghanaian regions of Ashanti and Volta. These regions were selected because they are known to have recorded the highest rates of treadle pump sales in Ghana. The Ashanti region recorded approximately 38% of total treadle pump sales while the Volta region recorded 15% of the total treadle pump sales in Ghana (EnterpriseWorks, 2004). The Ashanti Region lies in the south-central part of Ghana occupying an area of 24,389 km^2. The region falls within the Equatorial Monsoon belt, which is characterized by two main seasons, wet and dry. The wet season is associated with a double maxima rainfall regime from April to July (MAR=1270 mm) and September to October (MAR=1778 mm)[2]. The region is well endowed with rivers and lakes including man-made ones. Rainfed agriculture is predominantly practiced, and is associated with the cultivation of major staples such as maize, cassava, plantain, yam and some vegetables. Informal irrigation with the use of watering cans and buckets is extensively practiced in the dry season for the cultivation of both exotic and indigenous vegetables. In and around the capital city, however, vegetables are cultivated throughout the year, particularly exotic vegetables. These include lettuce, cabbage, carrot, spring onion, garden egg and green pepper.

The Volta Region is located in the eastern part of Ghana sharing the eastern border with the Republic of Togo. It is the fourth largest region in Ghana, covering a surface area of about 20,570 km^2. (Ghana Statistical Services, 2002). It has a mean annual rainfall of between 140 mm and 165 mm. The southern part of the region is located in the dry equatorial zone, which according to Dickson (1977, p.27) is the driest climatic zone in Ghana. Temperatures are generally high (between 26°C and 28°C) throughout

[1] Treadle Pump (TP)

[2] MAR: Mean Annual Rainfall

the year. The region's main river is the Volta, and is also served by several smaller rivers and streams. Farming is the dominant form of land use and the main source of income for most households in this region Duncan and Brants (2004). This is related to the predominantly rural character of the region and the fact that the region is moderately endowed with natural resources and fertile soils. Dry season vegetable cultivation is widely practiced and some districts cultivate vegetables throughout the year. Rainfed agriculture involves the cultivation of major staples including cassava, maize, rice and yam. Cocoa and coffee are important export crops cultivated in the forest zones. Fishing is another important income-generating activity, especially for communities along the coastline and Lake Volta. Both exotic and indigenous vegetables are irrigated and these include shallots, onions, okra, pepper and tomatoes.

2.2 Study Design and Data

The study was carried out primarily through a survey of 108 farmers comprising 52 adopters and 56 non-adopters of TP in the months of August and September 2005. In obtaining the sample for the survey, a multistage sampling technique was used. First, the districts in each of the regions with more adopters of TP were sampled using the sales list provided by EW. In all, five districts were selected in the Volta region and seven in the Ashanti region. Second, farmers in each selected district were stratified into two, namely adopters of TP and non-adopters. Adopters were identified by using the sales list and through assistance from sales agents. In some cases, farmers assisted in identifying other users. The non-adopters of TP were distributed throughout the selected districts. These were farmers who irrigated using the traditional water lifting devices such as rope and bucket and/or watering cans. Third, all TP adopters who were available in these districts were interviewed. Those who had stopped the use of the pump were also interviewed. In sampling non-adopters, a simple random sampling technique was used. A questionnaire was used to obtain farm and household level information from adopters and non-adopters. The data collected from the survey was supplemented by interviews with TP manufacturers and sales agents to distill information on the level of local capacity for the manufacture and dissemination of the TP. It is to be noted that the promotion of TP by EW in Ghana was only for a period of two years, only occurred between 2002-2004; hence, because the study was conducted in 2005, it was only able to assess the short-term impact of TP adoption in Ghana.

The data were analyzed using descriptive statistics and the Heckman's two-stage model. The T statistic and and chi-square statistic were used to test for significance in differences in the socio-economic characteristics of adopters and non-adopters.

3 Analytical Framework

3.1 Factors that influence adoption of TP

The decision to adopt an agricultural technology depends on a variety of factors (Nowak and Korsching, 1983; Wiersum, 1994; Mendola, 2005; Calatrava-Leyva *et al.*, 2005), including farm households' asset bundles and socio-economic characteristics, characteristics of the technology proposed, perception of need, and the risk bearing capacity of the household. An 'asset bundle' comprises physical, natural, human, social and financial assets. In this study, we hypothesize that the factors affecting treadle pump adoption are as follows:

Physical/natural assets – The area of land under irrigation is expected to affect the adoption decision. Farmers with less than a hectare of irrigated farm are expected to be willing to adopt the technology since the area is within the pump's capacity to irrigate. The size of irrigated land cultivated depends on availability and the financial capacity of the farm household for cultivation. It is therefore used as a proxy of the family's wealth status. Reliable access to water throughout the year is also considered a factor in whether or not the TP will be adopted.

Human assets – The quality and quantity of household labor are expected to affect adoption decisions. The quality of household labor is captured by the capacity to work proxied by the age of farm household head, and the capacity to adopt proxied by the level of education of household head. The quantity of household labor is captured by the household size and the ratio of family members that are not earning an income to those who earn (dependency ratio) and the number of household members who can assist in operating the treadle pump (those of 15 years and above). TP adoption is expected to have a negative relationship with the age of household head and dependency ratio; TP adoption is expected to have a positive relationship with the level of education of household head, household size, and household members above 15 years of age. The gender of the household head is included to examine its impact on adoption decisions, although no negative or positive relationships are hypothesized for this relationship.

Social assets – These are represented by membership in the farmers' cooperative society and frequency of extension visits. It is expected that membership in the cooperative society and high frequency of extension visits will increase adoption. These variables are expected to improve the adequacy of the information obtained about the pump, which will have an impact on the adoption decision..

Financial assets – This is proxied by the farm household access to formal or informal credit. Access to credit has remained a constraint to adopting improved technologies in developing countries and it is expected that access to credit will affect the adoption decision positively.

The adoption of TP technology can be analyzed by employing the logit or probit model. To assist in testing for selectivity bias in the outcome equation, however, the Heckman selection model was used to estimate both the adoption model and the poverty impact model (outcome equation). The explanatory variables in the adoption model are age of household head, years of schooling of household head, household size, household members above 15 years, dependency ratio, irrigated land area, membership of association, number of extension visits per year, gender, accessibility to credit, reliability of water and region.

3.2 Impact on poverty status of adopters

In order to further investigate the impact of treadle pump (TP) adoption on the poverty status of adopters, a multivariate analysis was done. To isolate the impact of TP adoption from other intervening factors, the establishment of a counterfactual outcome is required, as is the ability to overcome selection bias. According to HECKMAN and SMITH (1999), the establishment of a counterfactual outcome represents what would have happened in the absence of project intervention. ZAINI (2000) asserts that these problems become more complicated when participants self select into the project. Due to the difficulty of establishing an effective counterfactual situation, a control group was used. The control group comprises non-adopters of TP. To allow for selection bias in the assessment of the poverty impact of TP adoption, the identification variable approach following the Heckman two stage procedure was adopted to analyze the data. Selection bias relates to the unobservable factors which may bias the outcome on poverty due to TP adoption. An appropriate identification variable for this two step procedure needs to be found for the analysis. This variable has to influence adoption but not poverty. Moreover, even if an appropriate identification variable were found, the results from the procedure can be sensitive to the choice of this variable. Due to this limitation, the results from the procedure need to be checked for 'robustness' (ZAMAN, 2000). This paper adopted the 'number of extension visits per year' as the identification variable that influences adoption but not poverty. The choice is dictated by the fact that an increase in the number of extension visits increases farmers' knowledge about the TP and helps farmers make an informed decision as to whether or not to adopt. The impact of extension visit on poverty will depend not only on the number of extension visits per year but also on the quality of extension services rendered. The impact of this variable was tested in the adoption and poverty models to verify its choice as an identification variable.

The Heckman two stage procedure involves, first, the estimation of the adoption process and second, the estimation of the poverty outcome. Following ZAMAN (2000), the adoption equation (the first stage of the Heckman model) estimated is:

$$Y_i^* = \sigma + \delta X_i + \mu_i \tag{1}$$

Y_i^* is a latent variable representing the propensity of a farm household i to adopt TP, X_i is the vector of farm households' asset endowments, household characteristics and location variable that influence the adoption decision.
Prior to the analysis, pair wise correlation was conducted for the variables in the model and it was found that some of the variables were highly correlated. One of each pair of the highly correlated variables was dropped.

Employing the maximum likelihood estimation procedure, the probability of adoption is obtained from the first stage of the Heckman two-step technique. This involves employing a probit regression to predict the probability of adoption. Using these estimates, a variable known as the Mills ratio is obtained as follows:

$$\lambda_i = \frac{\phi(\rho + \delta X_i)}{\varphi(\rho + \delta X_i)} \tag{2}$$

Where ϕ is the density function of a standard normal variable,
φ is the cumulative distribution function of a standard normal distribution and
λ_i is the Mills ratio term

The second stage involves adding the Mills ratio to the poverty equation. The factors that determine poverty are explicit in the literature and they include household and community characteristics. Lack of household ownership and access to assets that can be put to productive use are important determinants of poverty (Ellis and Mdoe, 2003; World Bank, 2000). The specific factors identified in the literature that determine poverty include demography or human factors (e.g. household size, age and gender, education and health) and social capital (membership in mutual support organizations); physical capital (ownership of livestock and other productive assets); community factors (access to infrastructure and services, population density, urban-rural or regional location; and external factors (civil strife, climate) (Benin and Mugarura, 1999).

The household and community characteristics with institutional factors hypothesized to affect poverty are similar to those hypothesized to affect adoption. They are the age of the household head, household size, dependency ratio, number of years of schooling of household head, irrigated area, membership of water user or cooperative association, the geographical location of the study area and the household TP adoption status. The poverty status of the household is represented by its per capita income. The household per capita income was obtained by dividing the total household income by the number of adult equivalent in the household. The household income includes income from irrigated farming, rainfed farming, livestock production, off-farm activities, non-farm activities and remittances.

The poverty equation is estimated as:

$$P_i = \beta_0 + \beta_1 W_i + \beta_2 Y_i + \beta_3 \lambda_i + \xi_i \tag{3}$$

Where
$E(\xi_i) = 0$
P_i is the *per capita* income of household i in US Dollars
W_i is a vector of farm households asset endowments, household characteristics and location variable
$Y_i =$ is a dummy variable which is 1 for adopters and 0 for non-adopters

4 Results and Discussion

4.1 Socio-Economic Characteristics of TP Adopters and Non-adopters

The summary statistics of the socio-economic characteristics of adopters and non-adopters of TP are given in Table 1. It reveals that irrigated farming is male dominated with the percentage of males generally high in the study areas. The result also show that the age of household head was not significantly different for adopters and non-adopters.

There is a small but significant difference in the years of schooling of the household heads among adopters and non-adopters, with the former being more educated. The

Table 1: Characteristics of Adopters and Non-adopters of TP.

Characteristics	*Adopters*	*Non-adopters*	*% Difference*	*T-test / χ^2 value*
Age of Household head	41.38	43.32	4.68	1.041
Gender of Household head Male (%)	94.23	98.21	3.98	1.200†
Years of schooling of Household head	10.63	9.30	12.51	1.801*
Household size	5.97	6.78	13.56	1.693*
Adult male above 15yrs	2.14	1.98	7.48	1.042†
Adult female above 15yrs	2.12	2.21	4.25	0.358†
Dependency ratio	0.67	0.77	14.93	1.810*
Irrigated area	0.66	0.58	1.12	1.440
Member of Association (%)	48.07	55.35	7.28	0.572†
Number of extension visits per year	4.31	2.07	51.97	2.456***
Access to credit (%)	5.76	1.78	3.98	1.091*

*** significant at 1%, * significant at 10%, † chi-square (χ^2) values

mean household size of adopters is significantly lower than that of non-adopters. There is also higher numbers of adult males, and lower numbers of adult females in adopter households, but these differences were not significant. The dependency ratio of non-adopters is higher and significantly different at 10% from that of adopters. This implies that the ratio of non-working members to those working is higher in non-adopter households. Therefore, labor availability is lower in these households when compared with those of adopters. Adopters had higher number of extension visits per year (4.31) than non-adopters (2.07) and the difference is significant at 1%.

4.2 Factors that influence TP adoption

The explanatory variables and summary statistics used in the adoption model are presented in Table 2.

Table 3 presents the estimated parameters and the statistically significant variables explaining the adoption decision.

Diagnostic statistics (Table 3) showed that the model had a good fit to these variables with chi-square test statistics significant at 1%. This shows that the explanatory variables are relevant in explaining the adoption decision. The signs of the variables also agrees with *a priori* expectations, except the variable for age of the household head. The Z test statistics reveal that three of the variables were statistically significant. These were the dependency ratio, number of extension visits per year, and the regional dummy. Dependency ratio has a negative relationship with the probability of adoption and is significant at 1%. Increase in the number of non-working household members as compared to those working infers lower labor availability for productive economic activities. This apparently discouraged TP adoption, which requires labor for pedaling. Also, increase in

Table 2: Summary Statistics of the Explanatory Variables for Adoption Model.

Variables	*Explanation*	*Mean*	*Std. dev.*
Age of household head in years	Age of the household member responsible for final decisions on farm operations and investments	42.30	1.80
Year of schooling	Years of formal education of the household head	9.94	3.89
Household[3] size	Total number of members of the household	6.30	0.19
Household members above 15 years	The total number of household members above 15 years representing the adult workers in the household	4.23	2.26
Dependency Ratio	Ratio of non-income earning members of the household to income earning members of the household	0.72	0.01
Irrigated area	The area of land cultivated under irrigation before adoption	0.59	0.41
Membership of association	Dummy variable for membership of Water User Association, Farmer Cooperative Society; 1 for members, 0 for non-members		
Number of extension visit	Number of visits from MoFA and EW per year	3.10	1.83
Gender	Dummy variable for gender; 1 for male, 0 for female		
Accessibility to credit	Dummy for accessibility of credit from formal and/or informal sources: 1 for accessibility and 0 otherwise		
Reliability of water	Dummy variable for availability and accessibility of water all the year round; 1 for reliability of water, 0 otherwise		
Region	Dummy variable for region; 1 for Volta, 0 for Ashanti		

[3] A household is taken as members who eat from the same pot over a 12 month period

the number of dependants in the household may reduce the household income available for investments, thus discouraging adoption. The number of extension visits per year is positive and significant at 5% showing that the more frequent the number of visits, the higher the probability TP adoption. The regional dummy is significant at 5% and with a negative sign, implying that Ashanti region has a higher probability of adoption than

Table 3: Factors that influence Adoption of TP using Heckman Two-Stage Model.

Variable	*Coefficient*	*Standard Error*	*Z*	*P-value*
Constant	-0.261	0.724	0.361	0.717
Age	0.009	0.016	0.567	0.571
Years of schooling	0.050	0.041	1.211	0.226
Household size	-0.025	0.055	-0.464	0.642
Dependency ratio	-0.808***	0.280	-2.880	0.004
Irrigated area	0.248	0.363	0.683	0.495
Membership of association	-0.109	0.296	-0.370	0.711
Number of extension	0.067**	0.336	1.999	0.045
Reliability of water	0.358	0.309	1.159	0.274
Region	-0.766**	0.316	-2.421	0.015
Log- likelihood	-60.572			
χ^2	28.428			
Probability of χ^2	0.0081			
N	108			

*** significant at 1%, ** significant at 5%

the Volta region. In the Ashanti Region, there is easy access to big commercial markets particularly for exotic vegetables, which serves as an incentive for farmers.

This study shows that the age of the household head, years of schooling, irrigated area, and water supply reliability have positive relationships with the probability of adoption, but are not significant. Similarly, household size and membership in associations have negative relationships with the probability of adoption but are not significant. On the whole, this result revealed that availability of labor and increases in number of extension visits per year will increase the probability of adoption. In addition, there was a higher probability of TP adoption in Ashanti as compared to the Volta region

4.2.1 Impact on poverty status

A multivariate analysis was undertaken to assess the impact of TP adoption on poverty using the Heckman two-step procedure. Essentially, the explanatory variables include the same household and community characteristics, as well as institutional factors, as in the adoption model. The second step of the Heckman two-step procedure estimates the determinants of poverty and tests for selectivity bias by incorporating the Lambda into a linear regression. The Lambda is the inverse Mills ratio saved from the probit equation describing adoption. The dependent variable is the log of the household per capita income. The selection of the identification variable was tested by estimating the determinants of poverty. The model was estimated using the number of extension visits per year as the identification variable. Table 4 presents the coefficients in the poverty model from both the second step of the Heckman two-step and the OLS (Ordinary Least Squares) estimation procedures. The Lambda coefficient is negative and is not significantly different from zero which indicates the absence of selectivity bias in the sample. This means that the error terms of the adoption and poverty models are not correlated. The robustness of the identification variable was tested using the "identification on functional form" method. This involves including the identification variable in the model. Again, the Lambda coefficient was not significant. The identification variable was also not significant, which implies that it does not influence the per capita income of farm households in the study area. Therefore, it is possible to judge the variable appropriate for an identification variable. Since the results from the estimation can, however, be sensitive to the choice of the identification variable and in the two models the Lambda is not significant, the model can be estimated using an OLS.

Table 4: Determinants of Poverty.

	Heckman second step with number of extensions as identification variable		*Heckman second step and identifying on functional form*		*OLS estimation*	
Age	-0.001	(p=0.87)	-0.001	(p=0.89)	-0.001	(p=0.83)
Years of schooling	0.073***	(p=0.00)	0.073***	(p=0.00)	0.072***	(p=0.00)
Household size	-0.005	(p=0.78)	-0.005	(p=0.77)	-0.005	(p=0.78)
Dependency ratio	0.016	(p=0.85)	0.016	(p=0.86)	0.027	(p=0.76)
Irrigated area	0.739***	(p=0.00)	0.742***	(p=0.00)	0.749***	(p=0.00)
Membership of association	-0.031	(p=0.74)	-0.035	(p=0.71)	-0.036	(p=0.71)
Number of extensions			0.002	(p=0.87)	0.001	(p=0.91)
Reliability of water	-0.001	(p=0.98)	-0.002	(p=0.98)	0.007	(p=0.93)
Adoption of TP	0.247**	(p=0.04)	0.243**	(p=0.03)	0.281***	(p=0.00)
Region	-0.205*	(p=0.06)	-0.205*	(p=0.06)	-0.194*	(p=0.07)
Lambda	-0.012	(p=0.45)	-0.011	(p=0.44)		

*** significant at 1%; ** significant at 5%; * significant at 10%

The result from the OLS estimation is used to explain the model. The p values reveal that four of the variables are statistically significant and affect household poverty. Three of these have positive relationship with household poverty. They are; years of schooling, irrigated area and TP adoption. The regional dummy has a negative sign. The years of schooling of the household head is significant at 1 percent. The per capita income will increase by 7 percent for each additional year of schooling. This implies that the education of the household head had an impact on poverty. This is not surprising because literacy enhances the capacity to adapt to change, understand new practices and technologies, and improving a household's productivity and income. The size of irrigated area is positive and significant at 1 percent. A unit increase in irrigated area leads to about 74.9 percent increase in per capita income. Increase in irrigated area will increase farm output and incomes and thereby improve household per capita income. The adoption of the TP is significant at 1 percent. The result shows that the TP adoption increases per capita income by 28.1 percent relative to that of a non-adopter. This shows that the adoption of a TP reduces poverty. This is consistent with findings in a similar study in Malawi (Mangisoni, 2006).The regional dummy is significant at 10 percent and this implies that the per capita income of farm households in the Volta region was 19.4 percent lower than the per capita income of those in the Ashanti region. In sum, the increase in irrigated area has the highest impact on poverty followed by TP adoption, and lastly the number of years of schooling. The higher per capita income of farm households in Ashanti as compared to Volta is partly due to its better access to markets.

4.3 Conclusion

The paper examined the factors influencing the adoption of treadle pump technology for irrigation in two regions with the highest adoption rates in Ghana. The socio-economic analysis reveal that irrigated farming is practiced mostly by men irrespective of adoption status. There is no significant age differential between adopters and non-adopters of the technology. However, there are significant differences in the number of years of schooling, household size, dependency ratio and the number of extension visits per year between the adopters and non-adopters. The factors influencing the probability of adoption are the availability of labor and increase in the number of extension visits. The probability of adoption also differed between regions. The impact of treadle pump adoption on poverty revealed that the area cultivated under irrigation has the highest impact on household poverty. Others are the adoption of treadle pump and the number of years of schooling of the farmer. The impact on poverty also differed between regions due to access to markets.

The implication of these findings is that extension visits are important to technology adoption. Increased collaboration of private initiatives with local institutions such as extension service could improve the reach of the technology to farmers. Increasing the area cultivated under irrigation will reduce poverty: this suggests that assisting farmers gain access to land close to sources of water or drilling of tubewells to improve access to ground water will have significant impact on poverty reduction among poor farming households. It is also important to stress that due to the capital requirement for acquisition of treadle pump, targeted credit programs by formal financial institutions will ameliorate the financial constraint. This also will improve farmers access to the treadle pump because more farmers will be able to purchase the pump. The study shows the need for public-private partnership in the promotion and dissemination of agricultural technology to improve adoption rates.

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